Journal of the Nigerian Association of Mathematical Physics
***Volume34,(March, 2016*), pp 377 – 384**
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Experimental Investigation of Drying Rates of Solar Photovoltaic and Thermal Dryers. I-Comparison Of Drying Rates

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Abstract

Many experiments aimed at analysing and comparing the drying rates of agricultural products were carried out with the purpose of improving the output of farm products and quality of the drying equipment during convective drying. In this experiment, six similar solar dryer cabinets were constructed having five metallic sides and the top side covered with 5mm thick glass totrap infrared radiation for heat generation. Two of the dryers were painted black, another two were painted green while the last two were white aluminium. One set of the three colours was Unassisted Solar Powered Thermal Dryer (USTPD), while the other set was Integrated Photovotaic Solar Assisted Dryer (IPVSAD). Seven trays containing nearly equal weights (~3.4kg) of cassava chips were prepared. A tray of cassava chips was placed inside each of the six cabinet dryers while the seventh tray was placed in the open air to mimic the Traditional Open Air Dryer (TOAD). The drying rate of cassava was determined by continuously measuring the weight of cassava at specified time interval. The results showed that drying rate in the IPVSAD was faster than the USTPD. Similarly, the drying rate in the TOAD was higher than the USTPD.

Keywords: Infrared radiation, Solar Power, Thermal Dryer, Photovoltaic, Assisted Dryer.

1.0 Introduction

In the last decades, many experiments have taken place in the areas of dehydration of agricultural food products using solar energy [1].Complication arising from open air drying and the need for new generation equipment has resulted in various problems which has initiated this research work. A modified version of a hybrid photovoltaic-thermal integrated greenhouse dryer similar to the one that was developed and installed at IIT, Delhi was adapted for this research work. The floor area of the New Delhi experiment was 2.50 m × 2.60 m. The height at the center was 1.80 m and height of the side walls were 1.05 m from ground with 30° roof slope. The dryer was integrated with twoPhotovotaic (PV) modules on the south side roof. The PV module produces direct current (DC) electrical power to operate a fan for forced mode operation and also provides thermal heating to the greenhouse environment [2].A modified version of New Delhi experiment is a hybrid photovoltaic-thermal integrated 'green house' dryer with length of 0.46m, breadth 0.44m and height 0.27m inclined at angle of 10^o to the horizontal. The solar PV section consists of solar panel, charge controller, batteries for electric current's generation and storage, which provides alternative energy compensation for shortfall in the energy generated and supplied by the solar thermal source. Up to 70 per cent of agricultural products get spoil during the traditional process of open-air drying, especially in tropical and subtropical regions [3]. Average electricity prices for companies have jumped from 60% over the past five years because of costs passed along as part of government subsidies to renewable energy producers. Prices are now more than double in the United State of America [4].Farmers under subsistence agriculture sundry food products by natural sun drying, because the source of energy which is solar has advantage of being available to famers free of cost [2,5]. Solar drying is a dual process of: heat transfer to the product from the heating source, mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air [6]. Isiaka *et al.*[7] described convective solar energy drying as the transfer of heat energy from the surrounding environment to evaporate the surface moisture; the transfer of internal moisture to the surface of the material and its subsequent evaporation from the surface. Renewable energy such as

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wind, especially solar energy has many advantages; Solar Energy, an energy obtained from the sun, is the world's most abundant and cheapest source of energy available from Nature. It is free and automatically renewable every day. In the world over, emphasis has shifted from the use of hydro and fossil-powered electricity generation to renewable energy such as solar energy[8]. In Nigeria, less than 40% of the country is connected to the national electric grid and less than 60% of the energy demand of the country is generated and distributed [9]. An integrated dryer can be referred to as solar assisted dryer. An example of an integrated solar energy dryer is a grain-drying solar-assisted system which was described by Santos *et al.* [10]to be a solar collector which composed of a fan, an additional energy source for air heating, a plenum (for air distribution) and a bin batch drying system. Flat-plate collectors were used in air and water heating systems. The incident solar energy radiation from the sun is partially absorbed by a dark and opaque surface, part of this energy is transferred to the fluid and the remainder is lost to the environment. The collector plate is covered with a glass in order to minimize convective losses and create a "green house" effect.There are four major drying techniques; open air sun drying, firewood fuel drying, electrical drying and solar cabinet drying [11]. Over two thosand and two hundred papers have been published in the journal of solar energy of the International Solar Energy Society between 1957 and 1987; out of these only twenty three papers have been published in the area of solar drying. Furthermore only five of these papers were relevant to the drying problems being encountered by the majority of farmers in Africa [12]. Salawu*et al.*[13]used suns' energy to evaporate water from a freshly harvested crop and reduced the moisture content to a value which is of equilibrium with the surrounding during storage. Chua *et al*. [14] recommended intermittent drying as the best method suited for heat sensitive bio product such as food but this could have serious cost implication for farmers in the rural areas of Africa;they are often poor and are subsistence level practitioner [15]. According to [16]and Joshi *et al*. [17]convective solar energy drying operation is governed mainly by the properties of the drying medium (heat energy, air movement, humidity, atmospheric pressure and vacuum) and that of the product.

The main aim of this researchis to investigate the drying rate in an Integrated PV Solar Assisted Dryer (IPVSAD) and compare the outcome with those in the Traditional Open air Solar Drying (TOAD), and Unassisted Solar Powered Thermal Dryer (USTPD).The studyalso investigatedthe influence of environmental and physical parameters on the drying rates; compare, simultaneously, the drying rate of Cassava chips in Traditional Open air Solar Drying (TOAD) with Unassisted Solar Powered Thermal Dryer (USTPD), andIntegrated PV Solar Assisted Dryer (IPVSAD), identify the optimal performing dryer and also the effect of the inner colours of of the dryer'scompartments on the heat generated by the compartments during drying was investigated with a view of determine which of the solar energy dryers performed best.

2.0 Theoretical Consideration

2.1 The Useful Heat Gain Photo thermal Collector

$$Q_k \propto A\frac{dt}{dx} \tag{1}$$

$$q_k = KA\frac{dt}{dx} \tag{2}$$

For a plane wall

$$q_k = -\frac{KA}{L}(T_2 - T_1) = \frac{KA}{L}(T_1 - T_2) \tag{3}$$

$$A = \pi r^2 \tag{4}$$

L= Thickness of the wall.

$T_1 =$ temperature of left surface (x=0)

$T_2 =$ temperature of right surface (x=L)

In a steady state the useful energy output (Q_u) of a Solar Thermal Collector is the difference between the absorbed solar radiation and the thermal loss

where $$Q_u = AC\{S - UI(T_{p,m} - T_o)\} \tag{5}$$

Q_u	=	Total useful energy output
Ac	=	Solar Thermal Collector Area
S	=	Solar Radiation absorbed by the Collector
Ul	=	Thermal Energy Loss from Collector to the Surrounding by conduction, convection and infrared radiation
$T_{p,m}$	=	Difference between the mean absorbed plate Temperature
To	=	Ambient Temperature.

2.2 Useful Heat Gain by Solar PV Modules

The PV cell can directly convert the sunlight to DC power through the photoelectric phenomena. The power output of a single diode solar cell is given by Duffie and Beckman [18]. In short circuit condition, the diode current is very small and the light current is equal to the short circuit current.

$$\text{Ish} = IL - Ioe\frac{(V+IRs)-1}{\alpha} \quad (6)$$

$$P = IV \quad (7)$$

Where P=Power (in watts) generated by a single diode solar cell, Ish= Short circuit current (Module current), IL=Load current, α=Curve fitting parameter (V) and Io= Open Circuit current, [19].

Therefore Energy generated by the heat connected to a PV module = IVt which can be written as:

$$E = IL - Ioe\frac{(V+IRs)-1}{\alpha} \times V \times t \quad (8)$$

Where I, V is the current, Voltage of the connected ammeter and voltmeter and t is the time taken for the connected heater to be in working condition during the drying

2.3**Total Useful Heat Gain= Photo thermal Energy$_+$ Photovoltaic Energy**

Total useful heat gain by Integrated (PV) Solar Assisted Dryer (IPVSAD) and Unassisted Solar Thermal Dryer (USTPD) can be computed by adding equation (4) and equation (6) to give equation (9)

Photo thermal Energy$_+$ PhotovoltaicEnergy=

$$Qu = Ac\,\{S - Ul\ (Tp,m - To)\} + E = IL - Io(e\ \frac{V+IRs}{a} - 1) \times V \times t. \quad (9)$$

3.0 Methodology

Experimental Set Up-Solar Drying Experiment

Cassava chipsof average thickness $6.5 \times 10^{-3}\,m$, lenght $4.9 \times 10^{-3}\,m$ and breadth $4.35 \times 10^{-3}\,m$ (Table 1) was used to investigate the drying rate of the system of solar energy dryers because it is an important source of food foraverage Nigerian. Cassava (*Manihot esculenta*), also called kamoteng kahoy (in the Philippines), Paki or Ege in South western Nigeria, is the third largest source of food carbohydrates in the tropics, after rice and maize. Fauquetand Fargette[20]Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people[21].It is one of the most drought-tolerant crops, capable of growing on marginal soils. Nigeria is the world's largest producer of cassava, while Thailand is the largest exporting country of dried cassava, Kruckeberg and Arthur [22]. Average lenght, breath and thickness of 10 samples of cassava chips were picked at random, measured and recorded in Figure 1during the experiment as shown in plates 1, 2 and 3 respectively.

Table 1: Average Measurement of Samples of 10 pieces of Cassava Chips picked at random from the samples used during drying experiment

S/ No.	ThicknessX10-^{3}m	Lenght X10-^{2}m	BreadthX10-^{2}m
1	7.0	6.0	4.0
2	6.5	7.0	4.5
3	7.0	4.0	5.0
4	6.0	3.3	6.0
5	7.0	3.0	4.0
6	5.0	4.0	6.0
7	6.0	6.0	5.0
8	7.0	6.0	4.0
9	7.0	5.0	3.0
10	6.5	5.0	2.0
Averge	6.5	4.9	4.35

Plate1: Batches of Cassava Chips been weighed during drying experiment

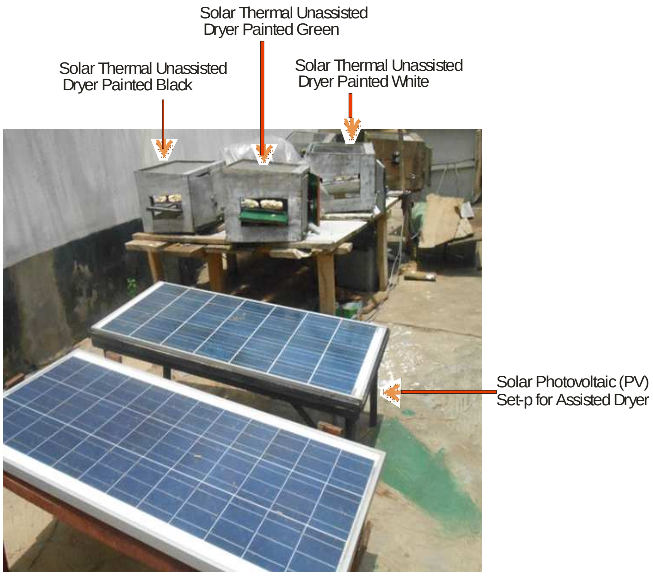


Plate 2: Drying Experiments Set Up Side A (Solar Thermal Unassisted Dryer)

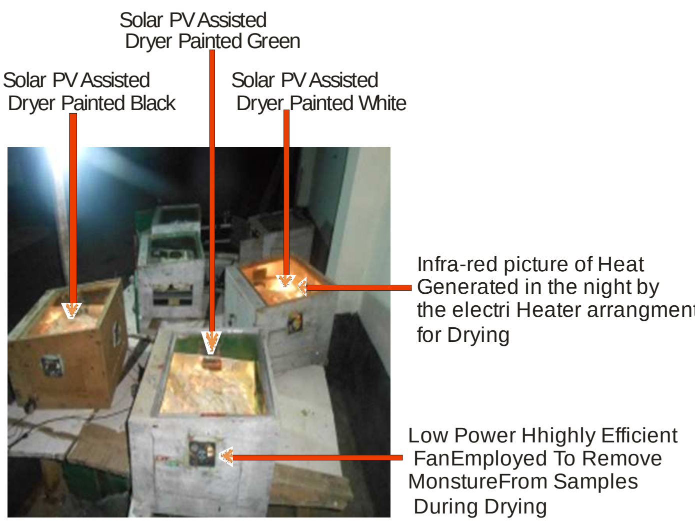


Plate 3: Drying Experimental Set Up- Side B- Integrated (PV) Solar Assisted Dryer (IPVSAD)- (Working Uninterrupted in the Night)

Six solar cabinet dryers were constructed (to be compared with the traditional open air drying) Figures 2, 3 and 4.Regarding drying of Agricultural commodities, there are four major drying techniques namely open air, fire wood, fuel drying, electrical drying and solar drying [23]. Six solar cabinet dryers are constructed and compared with the Traditional Open air drying as shown in Figure 1. Three out of the six solar dryers were solar thermal dryers, such as Thermal Black (TBLK), Thermal Green (TGRN) and Thermal White (TWHT).The other three solar energy cabinet dryers were 'assisted' with solar PV also as shown Figure 1.One of the three integrated solar cabinet dryers was painted black (IBLK), the second one green (IGRN), while the third integrate dryer was fabricated with (white) aluminium sheet (IWHT). At the three sides of each integrated solar cabinet dryer were located three low power consuming and highly efficient fans which remove moisture from the inside of the dryer chamber to the outside of the solar cabinet dryer. The process of expelling moisture continues until the required moisture content of the commodity is reached.

The attached thermostat performs the action of make and break at the pre-set temperature for the commodity to dry. A PV module power assembly was incorporated to produce electric current for the attached electric heater for generation of additional heat when the solar radiation becomes chaotic during the day or when it is not available in the night.

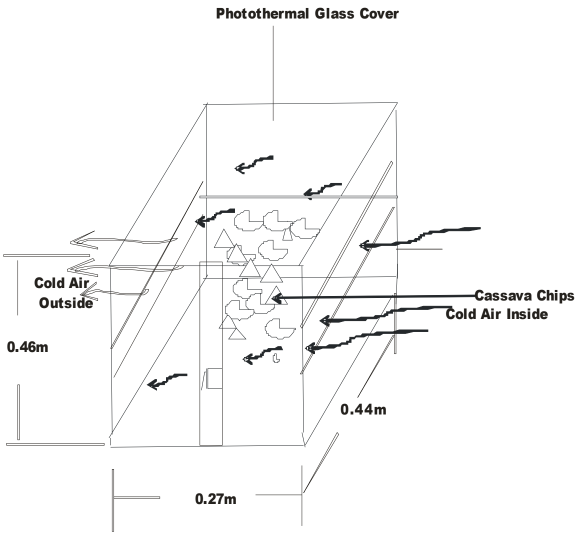


Fig 1: Drying Technologies- Geometry of an Unassisted Solar Thermal Dryer (USTPD)

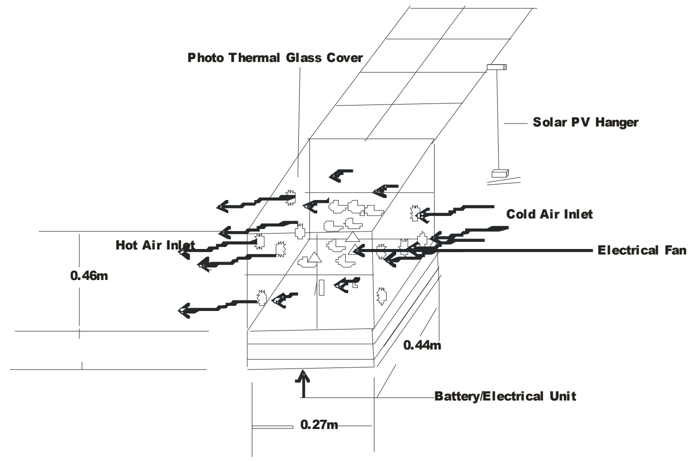


Figure 2: Drying Technologies- Geometry of an Integrated (PV) Solar Assisted Dryer (IPVSAD)

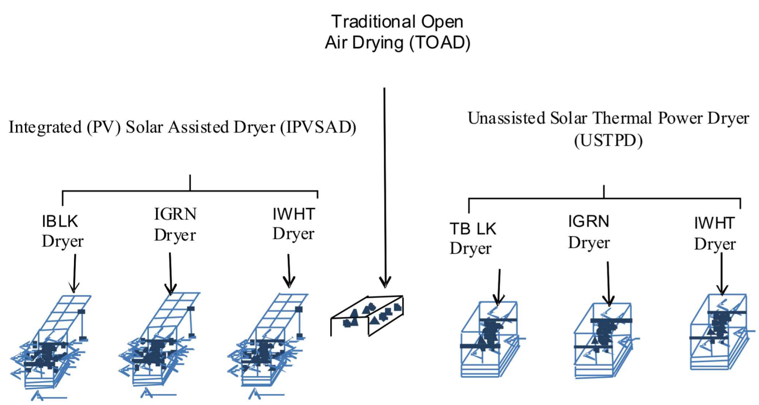


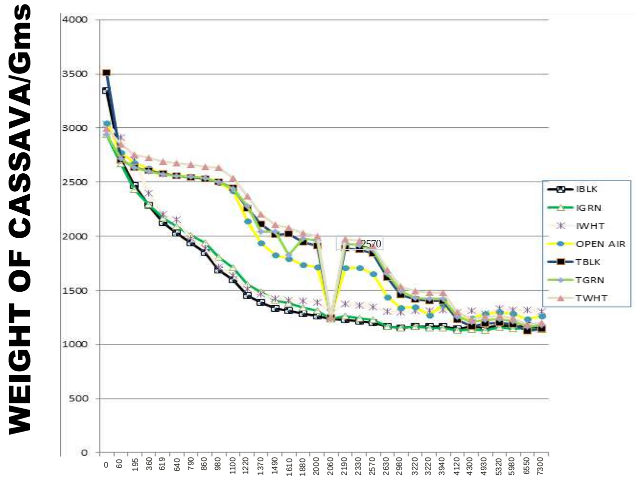
Figure3: Experimental Set-Up for Integrated (PV) Solar Assisted Dryer (IPVSAD) and Unassisted Solar Thermal Dryer (USTPD) Compared with Traditional Open Air Drying (TOAD)

4.0 Results and Discussion

Data was collected from the six systems of dryers and the Open Air Drying on each occassion of the drying process by weighing both the cassava chips and the tray before and after placing it inside the dryer for drying. The weight of the tray that contain the cassava chip was then subtracted from the total weight of cassava and the tray on each occassion and the result wasrecorded in Table 2. Table 2 presents thefinal weight loss for cassava at time tfor TBLK, TGRN, TWHT AND IBLK, IGRN and IWHT respectively during drying. The plot of moisture content (MC) of all the seven systems of dryers is presented inFigure 1. The drying rates (Figure 1)showed that they all theseven system of dryers,converged at the 17th number of recording or 2060 minutes of commodity drying. The weight of commodities at this point (17th number of recording or 2060 minutes) was taken as the value of the final moisture content (MC) for each of the dryers.

Table 2: Final Weight Loss for cassava During Drying

TRIALS		Integrated Dryers		Open Air		Thermal Dryers		Drying Time/Min.
	IBLK	IGRN	IWHT	open Air	TBLK	TGRN	TWHT	
1	3344	2939	3036	3041	3508	2937	2997	0
2	2703	2666	2912	2771	2006	2714	2850	60
3	2466	2434	2700	2676	2637	2637	2755	195
4	2286	2291	2398	2627	2606	2601	2722	360
5	2123	2167	2199	2580	3576	2569	2686	619
6	2031	2091	2152	2561	2555	2558	2672	640
7	1940	2008	1980	2551	2545	2548	2661	790
8	1848	1938	1891	2542	2530	2534	2641	860
9	1690	1802	1718	2495	2500	2499	2632	980
10	1600	1709	1637	2417	2445	2440	2535	1100
11	1452	1557	1510	2137	2260	2277	2366	1220
12	1389	1483	1464	1940	2111	2044	2201	1370
13	1333	1406	1425	1823	2011	2045	2108	1490
14	1312	1380	1411	1789	2024	1823	2076	1610
15	1280	1339	1399	1738	1946	1979	2029	1880
16	1260	1311	1388	1717	1913	1959	2002	2000
17	1233	1232	1293	1260	1251	1243	1251	2060
18	1230	1266	1375	1706	1889	1931	1971	2190
19	1212	1242	1360	1707	1877	1920	1959	2330
20	1198	1229	1344	1653	1840	1878	1913	2570
21	1166	1167	1303	1437	1618	1654	1685	2630
22	1151	1149	1294	1338	1456	1491	1532	2980
23	1168	1164	1314	1344	1414	1432	1491	3220
24	1162	1154	1312	1268	1405	1421	1480	3620
25	1164	1154	1316	1369	1405	1426	1477	3940
26	1146	1129	1300	1252	1225	1259	1297	4120
27	1162	1138	1311	1240	1163	1206	1233	4300
28	1153	1130	1285	1282	1191	1226	1258	4930
29	1181	1158	1331	1300	1199	1233	1263	5320
30	1168	1142	1321	1282	1184	1215	1241	5980
31	1173	1148	1319	1234	1124	1163	1185	6550
32	1150	1134	1304	1265	1143	1179	1201	7300



TIME/MIN.

Figure 4: Plot of combined Drying Rates of Seven Dryer Systems, (Weight against Time)

5.0 Conclusion

During the experimental investigation of drying rates of solar dryers, it was found that the three set of Integrated PV Solar Assisted Dryer (IPVSAD) performed better than the three set of Unassisted Solar Powered Thermal Dryer (USPTD) and the Traditional Open Air drying (TOAD). From the comparative graph analysis of all the seven systems of solar energy dryers investigated in this research work(Figure 4), the three sets of Integrated PV Solar Assisted Dryer (IPVSAD) was not affected by fluctuating weather condition therefore the major problem confronting the utilisation of solar energy dryer have been solved with this type of drying devise.

The results showed thatthe drying rate,among thethree sets IPVSAD with colours black, green and whiter, thedryer that was painted black dry faster than the other two dryers painted green and white; simiarly the same performance were repeated in the three set of USTPD withblack painted dryer dried cassava chips faster than the other two dryers with thier compatments painted green and white.

The convergence of moisture diffusion or moisture removal to 1200gms at the 2060 minutes of drying by all the three solar cabinet dryers and the Traditional Open Air Dryer (Figure 4 and Table 2) show that there exist a unique characteristic behaviour of cassava during unassisted solar energy drying when the Cassava is exposed to the atmosphere.

Further deductions from the plotted graph of moisture content (MC) and time (t) per minites (Figure 4) showed that the drying rates and the performance of the systems of dryers vary according to:

a. In both USTPD and IPVSAD, the black color paint performed best followed by green color paint, and then white color paint ..

b. IPVSADperformed better than the traditional open air drying and the USTPDcabinet dryers

c. Traditional open Air Drying performed better than the USTPDCabinet Dryer System.

d. USTPD performed least among the IPVSADand Traditional Open Air Drying

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